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ABSTRACT

A study of 130 undergraduate students enrolled in a course on audiovisual techniques sought to determine whether heuristic or algorithmic computer-based problem solving training would be differentially effective for students varying in cognitive complexity as measured by the Educational Set Scale (ESS). The interaction was investigated between one trait variable (cognitive simplicity-complexity), two treatment variables (heuristic or algorithmic training and numerical list or multiple choice response mode) in a math problem task. Dependent measures of interest were method of solution, total time in problem, and, for the list response mode group, total number of steps in the problem. Results indicated that compatibility in degree of structure between problem solving instructions and response mode led to performance that was stable across the continuum of conceptual preference. (CMV)

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Interaction Between Conceptual Level and Training Method in Computer Based Problem Solving

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Interaction Between Conceptual Level and Training Methods in Computer Based Problem Solving

INTRODUCTION

The purpose of this study was to investigate learner and instructional treatment variables posited to interact in a computer based problem solving task. Results may aid in the design of computer based instructional materials adapted to the individual prior to instruction.

TASK

The specific problem solving task of interest was the Water Jar Test (WJT) (Luchins, 1942) which consists of a series of mathematical problems that encourage students to develop a consistent strategy for solution in the beginning of the problem series but require a shift in method for successful solution in later problems. If the problem solver persists in trying to use the initial method of solution when it is no longer the most efficient or even a viable method, he is said to be responding in a mechanistic manner, or that his performance indicates susceptibility to "Einstellung" or "set."

A prior study by Brown and Sustik (1978) indicated that sudents using a numerical list response mode were most resistant to the inital development of mechanized responding, but that those using multiple choice were best able to overcome mechanization in later problems. This study did not focus on instructions that may impact performance measures, nor did it investigate possible interactions with relevant individual difference characteristics. Large variances resulted within response mode groups which may have indicated the presence of an individual difference dimension operating to increase the variances.

RATIONALE

Using a Trait-Treatment-Task-Interaction (TTT) strategy required identifying the individual difference dimension that may have influenced performance on the WJT. It was postulated that learners most susceptible to "set" would be those least inclined to generate and test additional hypotheses of solution methods. Conversely, multiconceptual learners would be less susceptible and more likely to overcome mechanization. Gagne's (1966) refers to this individual difference as "fluency in making new combinations" affecting the internal processes of combining subordinate rules and devising a provisional rule, and influenced by instructional efforts to guide thinking.

A specific dimension appropriate to performance variation in these problems is the cognitive-simplicity versus cognitive-complexity style. Persons who are cognitively-complex have sophisticated conceptual systems. As a result, they are more attuned to diversity, conflict, and uncertainty, such as might occur in WJT where a shift in solution is required, than the person who manifests an inclination toward cognitive simplicity.

Problem solving performance relevant to this dimension is affected by instructions. Tomlinson and Hunt (1971) found that a rule-example order of instruction resulted in better performance by low conceptual level students, while high conceptual level students were amenable to either inductive or deductive instruction.

Gordon (1977a), investigating the relationship between this cognitive style and the problem solving process, found that high conceptual level students provided more math examples prior to discussion of the rule in teaching a geometry unit than did low conceptual level students. Gordon (1977b) found that high conceptual level students chose a heuristic method of teaching problem solving while low conceptual level students chose a method which emphasized translating each verbal statement into a mathematical statement, without necessarily considering the whole. Gordon suggested that matching problem solving training method to cognitive style warranted further examination.

INDIVIDUAL DIFFERENCE MEASURE

This dimension has been investigated using the Educational Set Scale (ESS), a forced-choice objective measure by Siegal and Siegal (1965) to assess a student's preference for factual or conceptual material. "Educational set," is a continuum ranging from extremely factually oriented, interpreted as indicating cognitive simplicity, to extremely conceptually oriented, indicating cognitive complexity. A factually set person prefers to deal with discrete facts, adding units of information to his cognitive structure without relating them; a conceptually set person deals with facts by either ignoring them or incorporating them into existing systems. Most people tend to fall near the middle of this continuum but for those on the extreme, possession of either "educational set" may result in differing reactions to courses, materials, methodology, or instructors.

PROBLEM SOLVING TRAINING

The present study sought to determine if an instructional variable, heuristic or algorithmic problem solving training, would be differentially effective for students varying in cognitive complexity as measured by the ESS. Heuristic methods of problem solving teach the learner to develop a general process of problem solving while algorithmic methods teach a set of rules which can be used to solve a specific set of problems. Response modes used in CAI may interact with heuristic or algorithmic instructions. For example, the multiple choice response mode, wherein the student selects a correct solution equation from a list of possible solution equations, can be conceived of as being more closely aligned to the wholist heuristic approach. Similarly, a numerical list requiring specific stepwise completion of a given problem can be interpreted as being more amenable to the algorithmic training method.

RESPONSE MODES

Conceptualized in the TTTI framework, this study investigated the interaction between one trait variable (cognitive simplicity-complexity), two treatment variables (heuristic or algorithmic training and numerical list or multiple choice response mode) in a math problem solving task. The four combinations of method and mode were Heuristic-Multiple Choice (HMC), Heuristic List (HLIS), Algorithmic-Multiple Choice (AMC), and Algorithmic-List (ALIS). The dependent measures of interest were method of solution, total time in problem and, for the list response mode group, total number of steps in problem. Solution methods could be categorized as "no solution", "mechanized" if they were repetitions of previously used methods, or "non-mechanized" if they were more efficient than the repeated methods. Methods were accordingly assigned a "0", "1", or "2" with lower scores indicating less successful and more mechanized problem solving performance.

RESEARCH QUESTIONS

The specific questions to be answered were as follows. For dependent measures of method of solution in the WJT, total time in problem in the WJT, total number of steps in problem (for ALIS and HLIS):

1. Will there be a statistically significant interaction between ESS and instructional treatment?
2. If there is no interaction between ESS and instructional treatment, will there be a significant difference between instructional treatments?
3. If there is no interaction between ESS and instructional treatment, will the common beta for ESS be statistically significant?

MATERIALS AND PROCEDURES

PARTICIPANTS

Participants were 130 volunteer undergraduate education majors enrolled in a course on audiovisual techniques in the fall 1977 semester at the University of Iowa. Student participation facilitated familiarity with the computer as an instructional tool.

EDUCATIONAL SET SCALE

The Educational Set Scale (ESS) consists of 31 triads, using a total of 93 statements, which students rank to indicate their preference for learning situations. Scores are derived by assigning a −1 to each factually oriented situation ranked as the learner's first preference or to any conceptually oriented situation ranked as his lowest preferred learning

situation. Conversely, a +1 is given to each conceptually oriented situation ranked highest and to each factually oriented situation ranked lowest. Intermediate scores are given a 0. Potential scores thus range from −62, indicating a person with a highly factual set, to +62, indicating a person with a highly conceptual set.

The split-test (odd-even) reliability reported by Siegel and Siegel is .94 based on an n of 200 while the test-retest reliability (from 1 to 5 days later) was .92.

WATER JAR TEST

The Water Jar Test (WJT) consists of a series of problems in which three jars of different sizes are presented with instructions to obtain a given quantity by measuring back and forth among the jars. For example, three jars, called A, B, and C with capacities of 11, 25, and 5 quarts respectively are presented with instructions to obtain 4 quarts in any jar. This problem can be solved as follows: Fill Jar B and pour the contents into jar A leaving 15 quarts in jar B. Next, pour the contents of B into C, reducing the amount in B to 9 quarts. Empty jar C and again pour the contents of B into it, leaving the desired quantity, 4 quarts, in jar B. This solution can be represented as B−A−2C . Each problem is classified as a "set," "critical," or "extinction" problem as follows:

SET – solvable only by the B-A-2C or Einstellung method and designed to produce a mental set predisposing the student to use this method in subsequent problems.

CRITICAL – solvable by the B-A-2C or by a shorter more direct method and designed to test the susceptibility to set.

EXTINCTION – Not solvable by the B-A-2C method, requiring shift from previous methods to achieve success and designed to measure the ability to overcome set. In the basic study involving 1,039 subjects, 83% used the Einstellung method rather than a shorter direct method in the critical problems and 64% failed the extinction problem. A control group of 970 subjects received only the the critical and extinction problems. Not having had the set problems less than 1% used the B-A-2C method in the critical and only 5% failed the extinction (Luchins, 1959).

Luchins' original paradigm was used in this study, consisting of:

ITEM	PROBLEM	POSSIBLE SOLUTIONS	TYPE OF PROBLEM
1	11-25-5 get 4	B-A-2C	SET
2	21-127-3 get 100	B-A-2C	SET
3	14-163-25 get 99	B-A-2C	SET
4	18-43-10 get 5	B-A-2C	SET
5	9-42-6 get 21	B-A-2C	SET
6	20-59-4 get 31	B-A-2C	SET
7	23-49-3 get 20	B-A-2C A-C	CRITICAL
8	15-39-3 get 18	B-A-2C A+C	CRITICAL
9	28-76-3 get 25	A-C	EXTINCTION
10	40-118-18 get 62	2A-C	EXTINCTION

The WJT was presented to students on SuperBee CRT terminals operating from a Hewlett-Packard 2000 System. The driver program recorded time in problem, student response, and number of steps taken in each problem.

RESPONSE MODES

The problems were individually presented. At the top of the screen, the three jar sizes were displayed along with the desired amount. Beneath each jar, the current amount in each jar was displayed. Either a multiple choice or a numerical list response mode was used. With multiple choice, each problem had four possible solution equations plus a fifth No Solution option. If the student selected an equation that would solve the problem, that is, the Einstellung method in the set problems, either the Einstellung method or the direct method

in the critical problems, the direct method in the extinction problems, then he/she was told that his answer was correct and was shown the steps represented by the equation with the current jar values updated as the steps were taken. If he chose an incorrect equation, then he was told that he was wrong and was told to try again. If he chose a no solution option, feedback was given that there was a solution and he was advanced to the next problem.

Under the numerical list response mode, students were forced to proceed stepwise to solution by using the number of one of the following 16 possible steps:

1 FILL JAR A WITH WATER	9 POUR B INTO A
2 FILL JAR B WITH WATER	10 POUR B INTO C
3 FILL JAR C WITH WATER	11 POUR C INTO A
4 EMPTY JAR A COMPLETELY	12 POUR C INTO B
5 EMPTY JAR B COMPLETELY	13 SOLUTION IS IN JAR A
6 EMPTY JAR C COMPLETELY	14 SOLUTION IS IN JAR B
7 POUR A INTO B	15 SOLUTION IS IN JAR C
8 POUR A INTO C	16 NO SOLUTION

Thus "B-A-2C" would be represented as "2-9-10-6-10-14". As in the multiple choice mode, if the student solved the problem he was informed he was correct and given the next problem. If he chose the no solution option, he was advanced to the next problem.

SOLUTION METHODS

Each answer selected in the multiple choice mode or series of responses in numerical lists was categorized as a mechanized, direct or non-mechanized, or no solution method of solution via a computer program which performed this classification for data analysis, thus reducing possible human error in classification. Numerical list allowed students to use lengthier and atypical, but non-mechanized solutions such as "4A + B-2C" which were also classified as non-mechanized.

Students become familiar with using the terminal in a program that provided an overview of CAI. They ran three short programs, a tutorial discussing various factors which effect the cost of raising children, an example of computer based testing, and an example of the graphic capabilities possible on the SuperBee CRT. After the required session, those interested were given demonstrations of other programs.

HEURISTIC TRAINING

Students received heuristic or algorithmic instruction in problem solving. Heuristic instructions were designed after Polya's (1957) approach involving four basic steps: understand the problem, devise a plan, carry out the plan and evaluate the plan. This method emphasizes general understanding and consideration of multiple inputs to devising a plan. It was introduced by a problem of computing gasoline requirements for a long distance trip. The WJT was then introduced in the heuristic problem solving context. These students received a short message on the screen while solving problems which stated "REMEMBER DEVELOP AN OVERALL PLAN FOR EACH PROBLEM."

ALGORITHMIC TRAINING

Algorithmic instructions emphasized three steps: identifying a class of problems, determining a series of steps which can be used to solve these problems, implementing the steps to achieve solution. The algorithmic approach thus emphasized a step by step approach. The same basic problem of computing gasoline requirements for a long distance trip was solved using an algorithm, followed by introducing the WJT and the formula B-A-2C in algorithmic form. These students had a message displayed which said "REMEMBER THERE ARE SPECIFIC STEPS TO SOLUTION" along with each problem to reinforce using the algorithmic approach.

The Educational Set Scale was administered to students in their regular classes, machine scored, and used to sequentially assign students to one of the four treatment groups, Heuristic List (HLIS), Heuristic Multiple Choice (HMC), Algorithmic List (ALIS) or Algorithmic Choice (AMC).

All students received the general introduction to CAI and samples before being branched to the appropriate treatment program.

ANALYSIS

Questions were tested using the REGRESSION program from the (SPSS) (Nie et al. 1974). Analyses were conducted on data from all participants and on data from only those participants who successfully solved the final set items, referred to as the Luchin's Standard and in keeping with established literature. (All students, N = 130 Luchins Standard N = 101)

As described earlier, methods of solving problems were classified as "No Solution", "Einstellung" and "Non-Einstellung" and assigned a 0, 1 or 2 accordingly. This assumed a non-mechanized solution to be preferable to a repeated solution, and a repeated solution more desirable than no solution. The dependent measures for method of solution used this scale. For the analysis on multiple problems the values were summed across problems. Summation was also used in total time and total steps analyses. Addition of scores across problems permitted analyses on problems that were conceptually similar in the case of the critical or extinction problems, and across a variety of problem types when combining critical and extinction items.

RESULTS

INTERACTION: METHOD OF SOLUTION

In testing for interaction on method of solution, no interactions resulted when data from all students were included. Regression analyses on the Luchins' Standard revealed interaction in problems 7-8, problems 9-10, and problems 7-10 as indicated in table 1.

TABLE 1

Regression Summary Table for Overall Interaction on Methods of Solutions, Luchins Standards

	R^2 Full Model[a]	R^2 Reduced Model[b]	F[c]
Method 10	.26793	.22361	1.87
Method 7-8	.11760	.04154	2.67*
Method 9-10	.23085	.16335	2.80*
Method 7-10	.17058	.08244	3.40*

Note:
n = 101
[a] R^2 Full Model = R^2y ESS, D1, D2, D3, XD1, XD2, XD3
[b] R^2 Reduced Model = R^2y ESS, D1, D2, D3
[c] df = 3,93
* = $p < .05$

Pairwise comparisons demonstrated that the regression line for AMC differed from all others in problems 7-8, while for problems 9-10 the HLIS regression line was significantly different. Combining critical and extinction problems consolidated the previous analysis, yielding significant differences for all comparisons except AMC-HLIS.

The regression lines for these analyses, plotted in figures 1, 2 and 3 indicate that the AMC treatment facilitated performance for conceptually oriented students, particularly on the critical items, while it had a debilitating impact on performance by factually oriented students. The opposite relationship held for the HLIS treatment while variation in ESS score was not accompanied by variation in performance for students in the HMC or ALIS groups.

FIGURE 1

Regression Lines for Method of Solution in Problems 7-8:
Luchins Standard

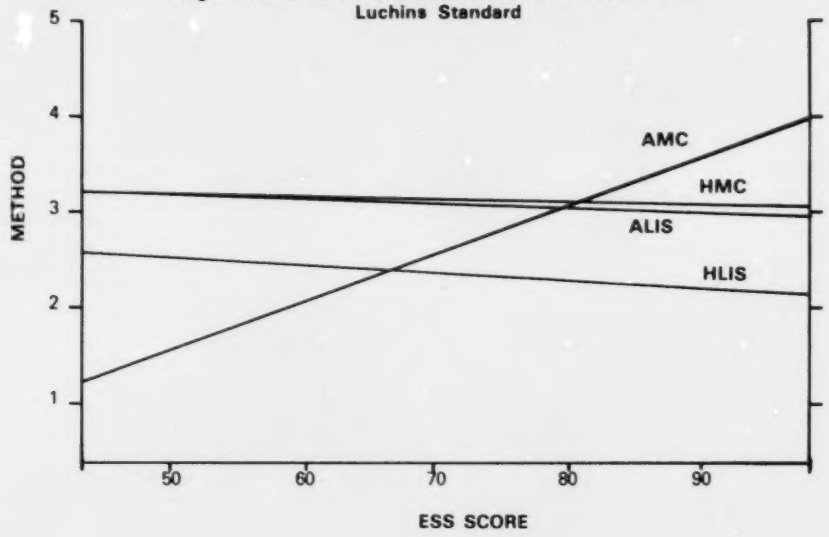


FIGURE 2

Regression Lines for Method of Solution in Problems 9-10:
Luchins Standard

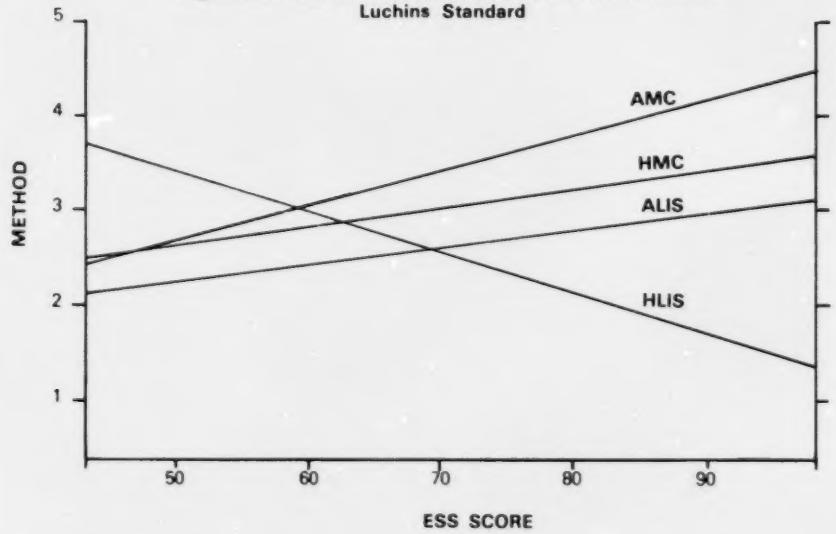
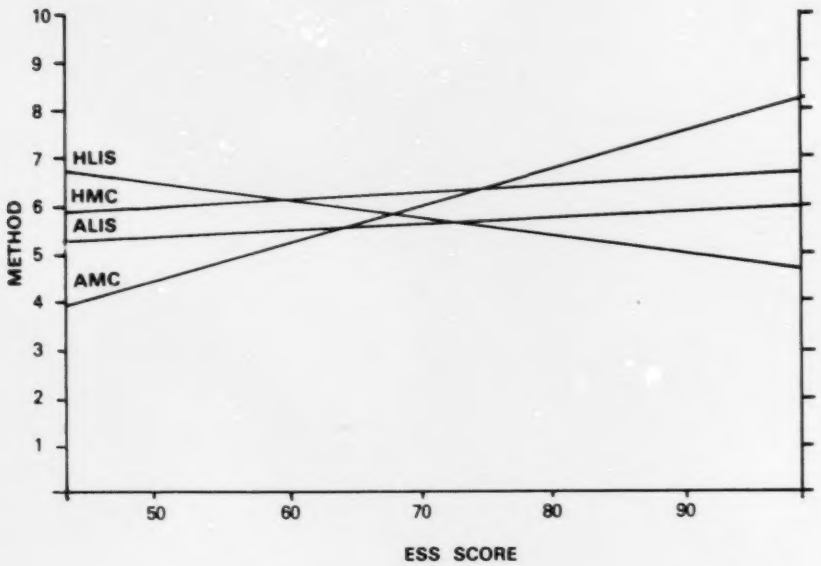


FIGURE 3

Regression Lines for Method of Solution in Problems 7-10: Luchins Standard



The results of the test for interaction on the total time measure indicated that no interactions were present when data from all students were included. Regression analyses on the Luchins Standard revealed interactions for problem 10, problems 9-10, and problems 7-10 as indicated in table 2.

INTERACTION: TOTAL TIME TO SOLUTION

TABLE 2

Regression Summary Table for Overall Interaction on Total Time in Problem, Luchins Standards

	R^2 Full Model	R^2 Reduced Model	F
Total Time 10	.30463	.23401	3.148*
Total Time 7-8	.39962	.38935	.530
Total Time 9-10	.34290	.26054	3.885*
Total Time 7-10	.45716	.37925	4.492**

Note:

n = 101

[a] R^2 Full Model = R^2y.ESS, D1, D2, D3, XD1, XD2, XD3

[b] R^2 Reduced Model = R^2y.ESS, D1, D2, D3

[c] df = 3,93

* = $p < .05$

** = $p < .01$

Pairwise comparisons indicated that the regression line for HLIS was significantly different from all other groups. Under this treatment, students with higher ESS scores spent less time in problem, than did the ESS continuum for students in the other treatments as seen in figures 4, 5, 6.

FIGURE 4

Regression Lines for Total Time in Problem 10:
Luchins Standard

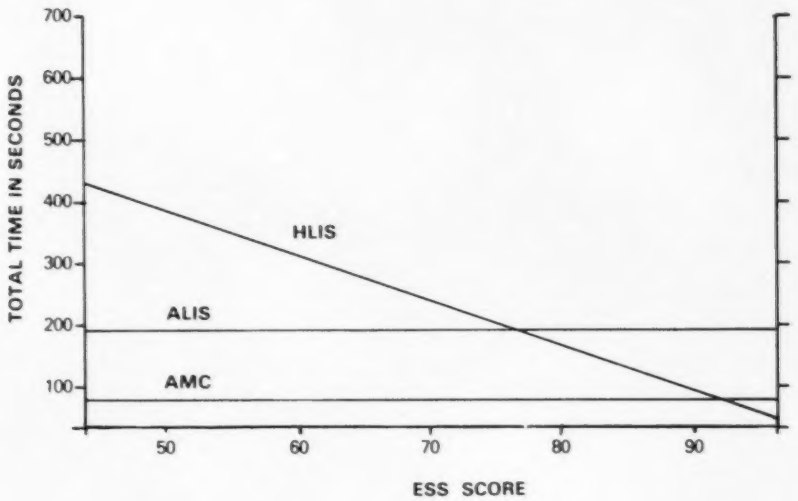
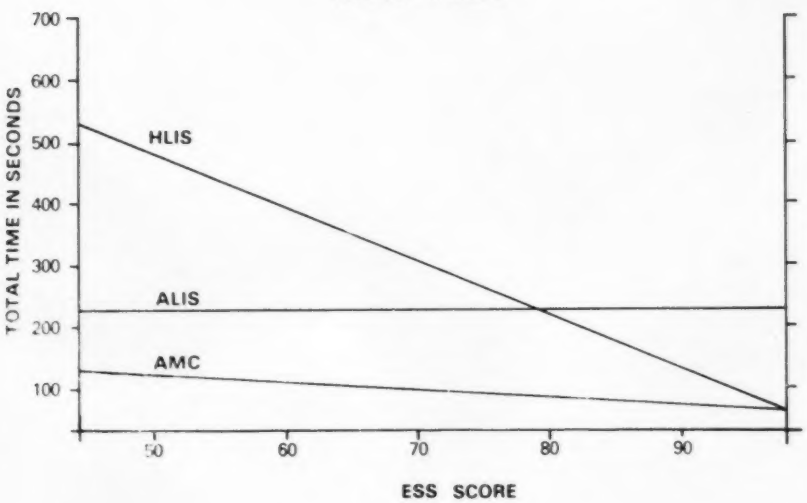


FIGURE 5

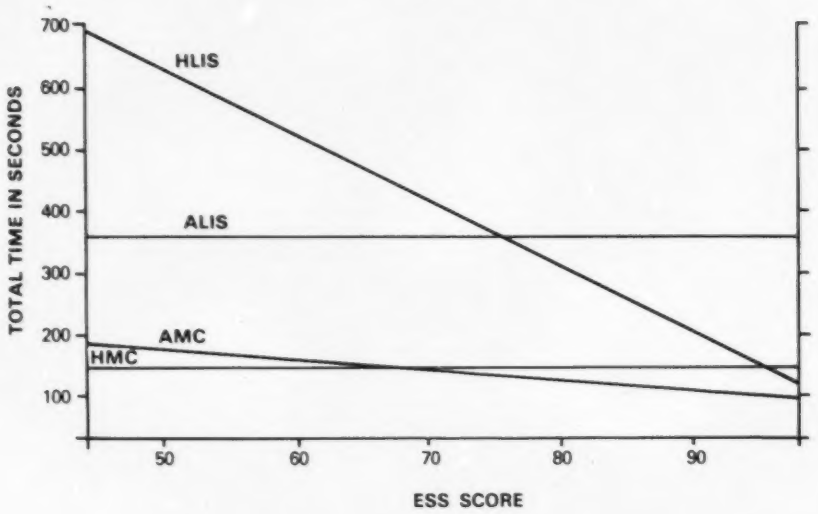
Regression Lines for Total Time in Problem 9-10
Luchins Standard



10

FIGURE 6

Regression Lines for Total Time in Problem 7-10
Luchins Standard



Again, in testing for interaction on the total steps measure, no significant interactions resulted when data from all students were analyzed. As seen in table 3, the interactions were significant on all dependent measures for the Luchins Standard, for steps in problem.

INTERACTION: TOTAL STEPS TO SOLUTION

TABLE 3

Regression Summary Table for Overall Interaction on Total Number of Steps in Problem for HLIS - ALIS, Luchins Standard

	R^2 Full Model[a]	R^2 Reduced Model[b]	F[c]
Steps 10	.32241	.11585	13.718**
Steps 7-8	.25143	.20114	3.02316*
Steps 9-10	.37944	.15688	16.139**
Steps 7-10	.38740	.17606	15.523**

Note:
n = 47
[a] R^2 Full Model = $R^2y.ESS, D1, XD1$
[b] R^2 Reduced Model = $R^2y.ESS, D1$
[c] df = 1,43
* = $p < .05$
** = $p < .01$

Regression lines, plotted in figures 7, 8, 9 and 10, indicate that conceptually oriented students took fewer steps in attempts to solve the problem than did factually oriented students under the HLIS treatment, while variation in conceptual preference was not accompanied by variation in number of steps taken in the ALIS treatment.

FIGURE 7

Regression Lines for Steps on Problem 10: Luchins Standard

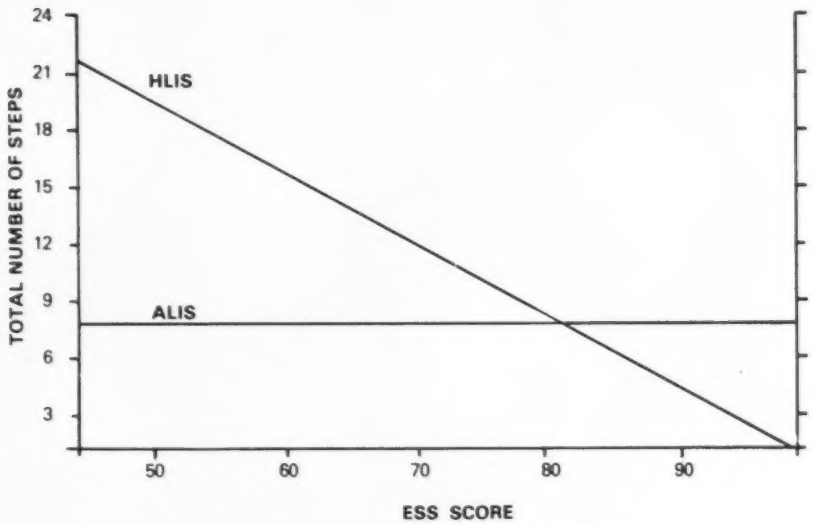


FIGURE 8

Regression Lines for Steps on Problems 7-8: Luchins Standard

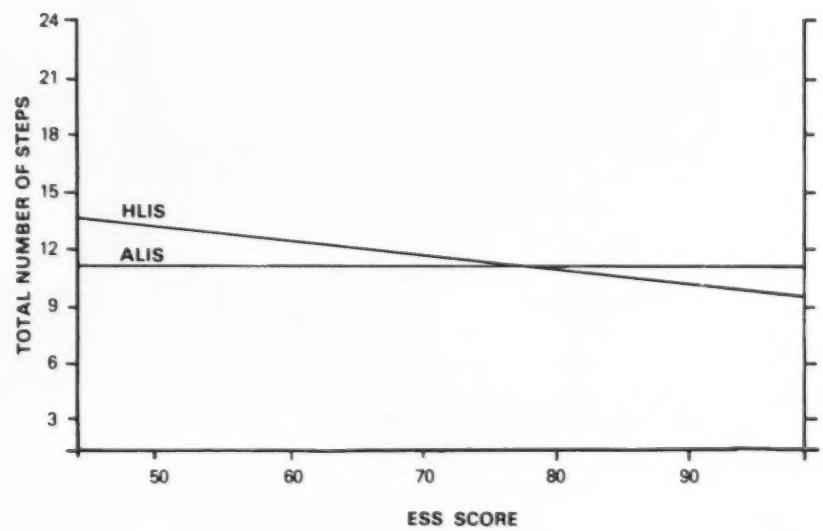


FIGURE 9

Regression Lines for Steps on Problems 9-10
Luchins Standard

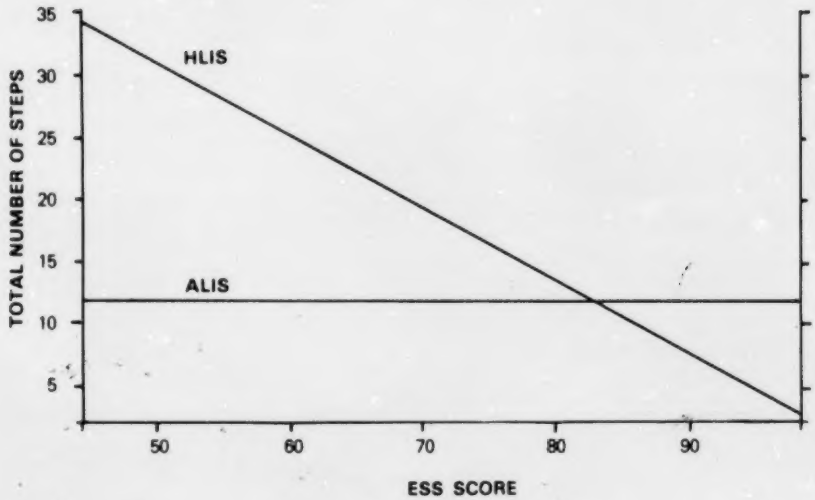
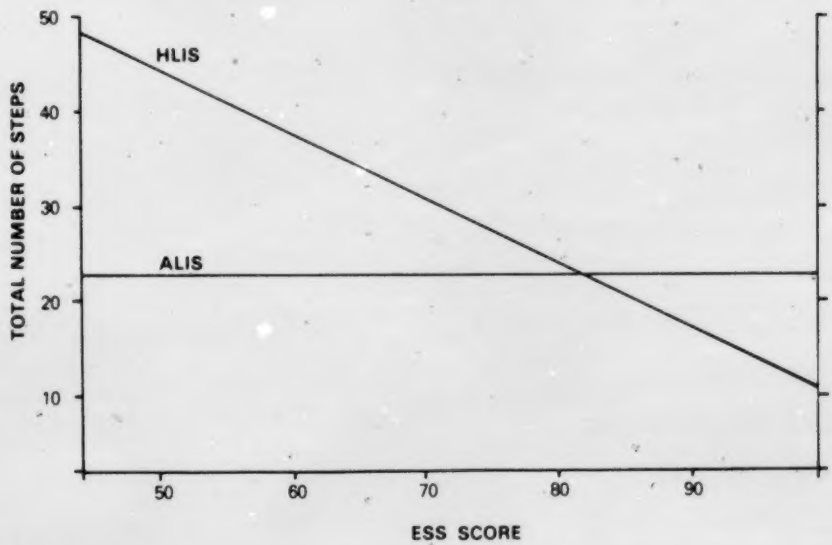


FIGURE 10

Regression Lines for Total Number of Steps In Problems 7-10:
Luchins Standard



GROUP DIFFERENCES: METHOD

In considering method of solution, as seen in table 4, group differences resulted in method in problem 10 which impacted analyses on problems 9-10 and 7-10.

TABLE 4

Regression Summary Table for Overall Group Differences of Method of Solution for All Students

	R^2 Full Model	R^2 Reduced Model[b]	F[c]
Method 10	.3039	.00434	18.257**
Method 7-8	.02266	.01466	.3374
Method 9-10	.24228	.00341	16.871**
Method 7-10	.16910	01087	7.4816**

Note:
n = 130
[a] R^2 Full Model = $R^2y.ESS, D1, D2, D3$
[b] R^2 Reduced Model = $R^2y.ESS$
[c] df = 3,124
** = $p < .01$

The results of the Dunn's multiple comparison follow-up test conducted on adjusted group means indicated consistent difference between the HLIS and all other treatments. The ALIS treatment also differed from the AMC and AMC treatments in some follow-ups. The multiple choice response mode groups yielded higher means than did the list response mode groups. Within response modes, the algorithmic training yielded higher means than did heuristic training.

GROUP DIFFERENCES: TOTAL TIME

For total time spent in problem, as shown in table 5, significant group differences were manifested for all total time measures.

TABLE 5

Regression Summary Table for Overall Group Differences on Total Time in Problem, All Students

	R^2 Full Model[a]	R^2 Reduced Model[b]	F[c]
Total Time 10	.15943	.01451	7.126**
Total Time 7-8	.36215	.00638	23.05**
Total Time 9-10	.19231	.02152	8.737**
Total Time 7-10	.32730	.02399	18.667**

Note:
n = 130
[a] R^2 Full Model = $R^2y.ESS, D1, D2, D3$
[b] R^2 Reduced Model = $R^2y.ESS$
[c] df = 3,124
** = $p < .01$

Conducting Dunn's multiple comparisons follow-up tests showed the only comparison that consistently was not significant was the HMC-AMC comparison. The group means for the list response mode groups were higher than for the multiple choice response mode groups as would be expected in light of the required stepwise input. While the means for the list groups were similar, the variance for HLIS was larger which may have accounted for the unexpected significant difference in these comparisons.

GROUP DIFFERENCES: TOTAL STEPS

In testing for group differences on total number of steps in problem, as seen in table 6, in analyzing data for all students, the HLIS and ALIS groups differed in the number of steps only in critical problems 7-8.

TABLE 6

Regression Summary Table for Overall Group Differences on Number of Steps in Problem HLIS, ALIS Groups Luchins Standard

	R^2 Full Model	R^2 Reduced Model	F
Steps 10	.18242	.16918	1.02023
Steps 7-8	.24753	.17109	6.39896**
Steps 9-10	.25272	.24849	.356613
Steps 7-10	.26017	.26014	.00255

Note:
n = 101
[a] R^2 Full Model = R^2y ESS, D1, D2, D3
[b] R^2 Reduced Model = R^2y ESS
[c] df = 3,61
** = $p < .01$

COMMON BETA: METHOD

The common beta weight for method of solution, as demonstrated in table 7, was significant only in critical problems 7-8, indicating that in these problems ESS significantly predicted problem solving performance as measured by the 0-1-2 scale.

TABLE 7

Regression Summary for Test of Common Beta for Method of Solution All Students

	R^2 Full Model[a]	R^2 Reduced Model[b]	F[c]
Method 10	55165	54890	760577
Method 7-8	18501	12883	8.54774**
Method 9-10	54401	54188	.579232
Method 7-10	42422	41116	2.81261

Note:
n = 130
[a] R^2 Full Model = R^2y ESS, D1, D2, D3
[b] R^2 Reduced Model = R^2y ESS, D1, D2, D3
[c] df = 1,124
** = $p < .01$

COMMON BETA: TOTAL TIME

The common beta weight for total time was significant only for extinction problems 9-10 as shown in table 8.

TABLE 8

Regression Summary Table for Test of Common Beta for Total Time in Problem, All Students

	R^2 Full Model[a]	R^2 Reduced Model[b]	F[c]
Total Time 10	.39929	.38109	3.7569
Total Time 7-8	.60179	.59398	2.43198
Total Time 9-10	.43854	.41495	5.20991*
Total Time 7-10	.62398	.61696	1.79224

Note:
n = 130
[a] R^2 Full Model = $R^2y.ESS, D1, D2, D3$
[b] R^2 Reduced Model = $R^2y.ESS, D1, D2, D3$
[c] df = 1,124
* = $p < .05$

COMMON BETA: STEPS

Unlike the previous two analyses, the common beta weight for steps consistently provided a regression equation which more accurately predicted number of steps than did the mean of these measures, as demonstrated in table 9.

TABLE 9

Regression Summary Table for Test of Common Beta Weight for Total Number of Steps in Problem, ALIS-HLIS Groups, All Students

	R^2 Full Model	R^2 Reduced Model	F
Steps 10	.17018	.05018	8.82119**
Steps 7-8	.24752	.14315	8.46078**
Steps 9-10	.25272	.09236	13.0901**
Steps 7-10	.26017	.04550	17.6998**

Note:
n = 64
R^2 Full Model = $R^2y.ESS, D2$
R^2 Reduced Model = $R^2y.D2$
df = 1,61
** = $p < .01$

SUMMARY, DISCUSSION AND CONCLUSIONS

While the WJT share similarities with problem solving in general, in discussing student performance it is necessary to bear in mind that the tests constitute a specific subset of problem solving situations. The primary interest is in mechanization of solution method in a mathematical problem solving series, that is whether using a single viable method in a series of problems will cause the learner to persevere on this method, precluding developing alternative methods in subsequent problems that require different methods to solution.

MECHANIZATION

The concept of mechanization is not without real world counterparts. Consider, for example, a physician who consistently employs a series of diagnostic tests to identify the cause of certain symptoms. In a situation analogous to the critical items in the WJT, there may be fewer, less costly, and less time consuming diagnostic tests which the physician could order; non-mechanized diagnosis would be preferred. Mechanization in extinction-type problem would, of course, be universally undesirable, since prior methods would negate deriving new techniques. The present study, however, used math problems established in the literature to assess mechanization.

PROBLEM SOLVING INSTRUCTIONS

In discussing the impact of the instructional treatment on performance, it is appropriate to consider the nature of instructions, as well as the response modes. The heuristic problem solving process relied on identifying components of the problem, stimulating recall of past similar problems where a method or parts of the method could be employed in the current context, and devising a plan pertinent to the problem at hand. This approach guides the process for developing a problem solving program, but does not guarantee success. It is a relatively unstructured problem solving approach, stimulating production of mental alternatives from which to build a strategy for solution.

The algorithmic problem solving process, by contrast, called for developing a more focused, highly structured series of steps that, once proven useful, could be employed in subsequent similar problems. While the heuristic process suggested development of a plan for each problem, the algorithmic process called for reinstituting a procedure that worked previously.

STRUCTURE

The multiple choice response mode presented several solution equations. In terms of structure, it was more compatible with the heuristic method, since each solution equation could be conceived of as representing a plan or program for solution. The numerical list, by contrast, in forcing students to proceed in a specific stepwise manner was more compatible with the algorithmic approach which stressed steps in a solution.

Structure imposed on the students in the instructional treatments is as follows:

TREATMENT	TRAINING	RESPONSE MODE
HMC	low	low
HLIS	low	high
AMC	high	low
ALIS	high	high

ALIS and HMC participants exhibited little variation in methods of solution or total time in problem along the ESS continuum. It appears that a match in the degree of structure elicited in the problem solving training and the degree of structure imposed by the response mode did not result in differential performance by factually or conceptually oriented students.

Disordinal interactions on the methods of solution occurred for the HLIS and AMC treatments where there was a mismatch between the problem solving training and response mode structure. Conceptually oriented students were less successful in problem solving under the HLIS treatment while factually oriented students performed well under this treatment. It is possible that conceptually oriented students, predisposed to a low degree of structure, were primed to think in an unstructured mode under the heuristic treatment and then required to respond in a highly structured stepwise manner, thereby motivationally impeding their performance. Or it may be that while they had the desire to solve the problems, they were not able to solve the problem using the list response mode. Conceptually oriented students in the HLIS treatment, however, also spent less total time in problem solving process than did the factually oriented students. This supports the possibility that high ESS students in this mode were less motivated to complete the problem, opting for the no solution option earlier than their low ESS counterparts.

SOLUTION VIA MULTIPLE CHOICE

Considering group differences, the rank order of the means on method of solution was AMC, HMC, ALIS, and HLIS for all students, and for the Luchins Standard. The multiple choice response mode allowed solving the problems in one of three ways. If students were mechanized to repeat the B-A-2C method, after the initial problem they may have visually searched for and selected this equation among the options presented. It was also possible for a student to develop an overall method of solution, or sequence of steps, and then choose the equation that corresponded to this method. Finally, a student could covertly employ each equation presented and select the equation which would solve the problem. While it is impossible to state which of these procedures were used by students in the multiple choice response mode groups, obtaining higher means under the multiple choice than under the list mode suggests that the latter method was used predominantly.

Group differences indicating that less total time in problem was spent by students in the multiple choice response mode groups than the list response mode groups can be accounted for by the fact that the numerical list required input on a step basis, while only one input, the selection of the correct equation, was required in the multiple choice modes. Considering the above implies that the time required to recognize an equation or to devise a plan, convert it to a solution equation, and identify that equation from those presented, or the time to covertly solve the equations presented in order to identify the correct equation, is less than the time required in the list modes.

The ESS common beta was not consistently significant across measures to justify its use in predicting either method of solution or total time in problem when all four treatments were considered. In considering only the HLIS and ALIS groups, it was useful for predicting total number of steps for all students.

It has been shown that interactions resulted only in analyses done on date for students meeting the Luchins Standard. The restriction from all students to the Luchins Standard did not impact group means for HMC, AMC, or ALIS groups. The means on method of solution and total time in problem for the HLIS group under the Luchins Standard were higher than when data for all students were included. This indicates that students in the HLIS group who failed to solve problems 5 and 6 spent less time in problem and were less successful in solving problems 7-10 as well than students meeting the Luchins Standard. This performance by the HLIS group was most notable in problem 10.

ITEM 10 DIFFICULTY

Problem 10 is of interest by itself; in a prior as well as the present study, this item was found to be more difficult for all students regardless of treatment.

A plausible explanation is that the problem solving process for successfully solving this problem was more complex than for solving the other problems. Not only did problem 10 require a non-mechanized method, but it required a more complex non-mechanized method than did problem 9.

Consider again the problem series. Problem 7, a critical item, and problem 9, the first extinction item, both permitted a "A-C" solution which required using only jars A and C. Problem 8 required an "A + C" solution and required using all three jars, and jar B was used only as a receptacle for the contents of A and C. In Problem 10, however, the solution was lengthier, "2A-C", using all three jars. Additionally, jar B was used as a receptacle for twice the contents of jar A, and also served as the source for pouring into jar C. Hence Problem 10 is more difficult in terms of length of solution and in number of uses of the jars given. It is possible that Problem 10 would have shown a higher success rate had it occurred earlier in the series without receiving prior interference of the other shorter methods, or it may be that beyond set, this item was inherently more difficult.

Although item 10 presented greater difficulty to students in all four treatments, depressed performance was most notable in the HLIS treatment group. It may be that the HLIS treatment accentuated anxiety due to the mathematical nature of the problems more than the other treatments. The aversion to math problems is typically higher in females, who constituted the majority of the sample population, than it is in males. It is impossible without further investigation to discern whether the pronounced performance of the HLIS group was attributed to any of the causes discussed.

CONCLUSIONS

The following conclusions appear warranted by the data.

1. Compatibility in the degree of structure between problem solving instructions and response mode results in performance that is stable across the continuum of conceptual preference.

2. A mismatch in the degree of structure between instructions in problem solving and response mode will result in differential performance across the conceptual preference continuum. Conceptually oriented students will profit from structured problem solving training followed by an unstructured response mode. These students will perform poorly after receiving low structured instructions if forced to respond in a highly structured manner. Conversely, factually oriented students will be facilitated by low structure problem solving instructions followed by a high structure response mode. When there is a mismatch in structure of training and response mode, the response mode draws more heavily on conceptual preference: factually oriented students profit from high structure and conceptually oriented students profit from low structure in response mode.

3. In analyzing the Water Jar problems, interactions resulted only on analyses that employed the Luchins Standard.

4. Students using a multiple choice response mode in general exhibit less mechanization and spend less total time in problem than students using a numerical list response mode in solving math problems of this type.

5. The common beta for Educational Set Scale does not significantly predict student performance as measured by method of solution or total time in problem in math problems of this type.

LIMITATIONS

The following limitations are acknowledged in considering the results of the present study.

1. The Water Jar Test represents a specific subset of problem solving situations, focusing on mechanization in a mathematical problem solving series. Generalizations relating to the appropriateness of the instructional treatments used in conjunction with conceptual preference cannot be generalized beyond this domain of problem types without further investigation.

2. While the WJT are established in the problem solving literature, they are normally administered in a paper-pencil format. The problems in this study were administered via CRT terminals. Comparisons with previous WJT literature may be restricted since the effects that presentation via CRT rather than paper-pencil may have had on performance were not assessed.

3. The algorithmic and heuristic instructions that students received prior to solving the WJT were restricted to approximately a 15-minute interactive segment. It is possible, if not probable, that more extensive instruction in these methods may have interacted with ESS or manifested group differences in a different manner or magnitude.

4. The majority of participants was female. It is not appropriate to generalize findings to a population representing different proportions of males and females.

5. Most students had little or no prior familiarity with computer based programs. While the introductory segment on CAI was presented before the instructional treatments and the WJT in an attempt to provide basic familiarity with the CAI medium, it is possible that students with a stronger exposure to CAI may have responded differently.

The general goals of Trait-Treatment-Task-Interaction studies are to explain performance and to guide in the design of instruction. Most research gives rise to questions concerning both the explanation of behavior and the validity of instructional recommendations best answered by further investigations. The following recommendations, therefore, subsume both areas of suggestions for the design of instructions and for future investigations.

RECOMMENDATIONS

1. The heuristic and algorithmic instructions should be expanded to include more examples and practice using these methods prior to completing the problem solving series. This would increase the likelihood that the essential concepts of each approach were internalized by the student and in fact used in the subsequent problems. Additionally, the impact on students with different conceptual levels may differ with greater familiarity in either of these methods.

2. Experiments should be designed which would more directly assess the processes which students use in the problem solving series. This would substantiate present explanation of behavior or would more accurately identify the critical elements of instructions and responding which affected problem solving performance.

3. The complexity of problem solving requires that we begin with lab based situations such as the water jar problems prior to extrapolating to real world situations. However, it would be appropriate to extend the investigation of the relationship between conceptual level and computer based problem solving performance with material which typifies the content of instructional programs.

4. In developing only one treatment, it may be advisable to use the multiple choice response mode in computer based materials of this type. Given the relative increase in time and effort to prepare programs to use the numerical list mode, there was no overwhelming evidence to support the use of this more elaborate answer processing format.

5. Models of microadapting in problem solving should be developed that would vary the level of difficulty, number of cues, number of practice items and nature of feedback to improve problem solving performance.

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